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A GA-based fuzzy optimal model for construction time–cost trade-off

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Abstract

Owing to different resource utilization, activity duration might need to be adjusted and the project direct cost could also change accordingly. Moreover, activity duration is uncertain due to variations in the outside environment, such as weather, site congestion, productivity level, etc. A new optimal construction time–cost trade-off method is proposed in this paper, in which the effects of both uncertain activity duration and time–cost trade-off are taken into account. Fuzzy set theory is used to model the uncertainties of activity durations. A searching technique using genetic algorithms (GAs) is adopted to search for the optimal project time–cost trade-off profiles under different risk levels. The method provides an insight into the optimal balance of time and cost under different risk levels defined by decision makers. © 2000 Elsevier Science Ltd and IPMA. All rights reserved.

Keywords: Time–cost trade-off; Fuzzy set; Genetic algorithms; Construction scheduling

1. Introduction

Since the late 1950s, Critical-Path-Method (CPM) techniques have become widely recognized as valuable tools for the planning and scheduling of large projects. In a traditional CPM analysis, the major objective is to build up the feasible duration required to perform a specific project. However, in a real construction project, project activities must be scheduled under available resources, such as crew sizes, equipment and materials. The activity duration can be looked upon as a function of resource availability. Moreover, different resource combinations have their own costs. Ultimately, the scheduler needs to take account of the trade-off between project direct cost and duration. For example, using more productive equipment or hiring more workers may save time, but the project direct cost could increase. In general, the less expensive the resources used, the longer it takes to complete an activity. Finding the most cost effective way to complete a project within a specific completion time is desirable for schedule planners. Several mathematical and heuristic models have been generated to solve construction time–cost trade-off problems [4,9,20,23,24]. These models mainly focused on deterministic situations. However, during project implementation, many uncertain variables dynamically affect activity duration, and the costs could also change accordingly. Examples of these variables are weather, space congestion, productivity level, etc. To solve problems of this kind, some systematic methods, such as PERT, PNET and Monte Carlo simulation, have been developed to deal with uncertainty in the project duration. Nevertheless, these non-deterministic scheduling methods seldom take account of time–cost trade-off. Therefore, combining the aforementioned concepts to develop a construction time–cost trade-off model under uncertainty would be beneficial to scheduling engineers in the forecast of a more realistic project duration and cost. Such a model could generate additional management information, such as the relationships between project duration and cost, level of sensitivity of an activity to specific uncertain variables, and the interactive effects of both factors. Based upon the information, project management can take appropriate timely action to provide the optimal balance of time and cost.

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This paper adopts a new approach, employing genetic algorithms (GAs) and fuzzy set theory to develop a construction time–cost trade-off model under uncertainty. In this model, the activity duration is characterized by a fuzzy number. An acceptable risk level (i.e., α-cut level) is then defined as the minimum condition that can be accepted. Genetic algorithms are then used to search for the minimum project direct costs for a specific project duration within feasible project time spectrums. In other words, the focus of the model is to find time–cost trade-off curves based upon different risk levels defined by decision makers.

2. Literature review

Time–cost trade-off analysis is one of the most important aspects of construction planning and control. Based upon whether activity duration is certain or not, construction time–cost trade-off models can be categorized into two areas: deterministic scheduling and non-deterministic scheduling. Traditional construction time–cost trade-off models mostly focus on deterministic situations.

The most popular techniques of deterministic time–cost trade-off scheduling models are analytical and heuristic methods. Linear programming and dynamic programming are the two types of mathematical programming methods generally used to solve time–cost trade-off problems [4,15,20,25]. In these methods, the relationships between activity costs and durations are generally assumed as: 1) linear or nonlinear; 2) concave, convex, or not fixed; 3) discrete or continuous; or 4) hybrid. Mathematical time–cost trade-off models require a great deal of computational effort so that they only suit small-size projects [23]. Some heuristic methods have also been generated to solve time–cost trade-off problems. Most heuristic methods generally assume linear time–cost relationships within project activities [14]. These methods provide good solutions, but do not guarantee optimality. Fondahl's method [9], Siemens's effective cost slope model [24], and Moselhi's structural stiffness model [21] are examples of heuristic approaches [9,21,24]. Recently, some researchers have adopted computational optimization techniques, such as genetic algorithms and simulated annealing, to solve construction time–cost trade-off problems. Feng [8] and Chua [6] proposed models using genetic algorithms and the pareto front approach to solve construction time–cost trade-off problems [6,8]. The above-mentioned time–cost trade-off models mainly focus on deterministic situations.

Construction management has recently begun to pay attention to non-deterministic scheduling due to the many uncertain variables involved in construction operations. Classical non-deterministic scheduling models are PERT and Monte Carlo simulation, and they are the ones most widely used in practice [7]. Ang [2], Ahuja and Arunachalam [1], Padilla and Carr [22], Gong [11] and several others also developed scheduling models under uncertainty [1,2,11,22]. These models are mainly based upon probability theory. Other researchers have claimed that fuzzy set theory is appropriately used to model uncertainty that is associated with time elements in project networks [5,17,19]. Due to a sheer lack of information about activities, the values of project variables are often estimated by human experts. Many of the values are defined based upon fuzzy and/or incomplete information. This type of information might be best modeled by fuzzy set techniques instead of probabilistic ones. Ayyub and Haldar [3], Hadipriono and Sun [12], Wang [26], Wu and Hadipriono [27], Lorterapong [17], Hapke and Slowinski [13], Lorterapong and Moselhi [18] and several others proposed fuzzy-set-based models to tackle construction scheduling problems under uncertainty [3,12,13,17,18,26,27]. The aforementioned non-deterministic construction scheduling models mainly focus on the impact of time variation on project duration, or further take resource constraints into consideration. To the knowledge of the authors, none of the non-deterministic construction scheduling models has been proposed to solve time–cost trade-off problems.

In this paper, the authors integrated ideas from the aforementioned research in a new approach using fuzzy set theory and genetic algorithms (GAs) to tackle construction time–cost trade-off problems under uncertainty. The goal of the paper is to establish a fuzzy optimal construction time–cost trade-off model. In this model, the activity duration is characterized by a fuzzy number. An acceptable risk level (i.e., α-cut level) is then defined as the minimum condition that can be accepted. The GA techniques are further used to find optimal or near-optimal solutions within the fuzzy solution space.

The following sections briefly introduce the concepts of fuzzy set theory and the genetic algorithms that are used in this paper. Next, the fuzzy time–cost trade-off algorithms are discussed and its mathematical forms are described. A GA-based algorithm for solving the problem is then given. A standard test example is presented to demonstrate the operation of the algorithm. The conclusions are made in the last section.

3. Fuzzy set theory

Fuzzy set theory was developed specifically to deal with uncertainties that are not statistical in nature [16,28]. Let A be a fuzzy number, i.e., a normalized convex fuzzy subset of real line X: $A=\{(x,\mu_A(x))|x\in X\}$, where $\mu_A(X)$ is a membership function taking values